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Sonographic anatomy of the fetal cerebral ventricles, with reference to the early diagnosis of hydrocephaly

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1 Introduction

Fetal intracranial anatomy can be identified in utero utilizing real time ultrasonography. Many studies have focused on these measurements for the diagnosis of hydrocephalus. DENKHAUS and WINSBERG [3] measured the frontal horns, an area considered to be the third ventricle, the distance between the temporal horns, and the distance between the sylvian fissures, from 13 weeks to term. JOHNSON studied normal fetuses and measured lateral ventricular width (LVW) and hemispheric width, and calculated the LVW/HW ratio [6]. HADLOCK measured the lateral ventricular ratio at the body and atrium of the ventricle [4]. These investigators used the sonographic anatomy to attempt the early diagnosis of hydrocephalus. The present study utilized the same approach, with all these measurements as well as maximum ventricular length and width. Measurements of maximum ventricular length and width were considered to be of potential value in order to improve on the early diagnosis of fetal hydrocephaly. These measurements were made in the neonatal fixed brain as well, for comparison. These studies might permit the diagnosis of intracranial abnormalities, as well as define the normal development of the fetal cerebral ventricles.

2 Materials and methods

The measurements of the ventricular system, anterior horn (AH), maximum ventricular length (MVL) and width (MVW) and midbrain (MB) were performed on 151 obstetrical patients from 16 weeks to term. The gestational ages were based on the last menstrual period, early examination, and biparietal diameter (BPD) using the nomogram of HOBBINS et al. [4]. All examinations were done using the linear array (ADR), TEMPE, Arizona, with the 3.5 mHz transducer. Serial transaxial sections were taken at four levels from the outer cortex progressing caudally to the level of the midbrain. Level 1 is a measurement taken at the anterior horns between the two echogenic linear structures (Fig. 1). Level 2 is a measurement of the MVL and MVW (Fig. 2). Level 3 is taken at the level of the BPD. The cavum septum pellicidum is visualized as two echogenic linear structures anterior to the thalamus. The thalamus is echolucent except for the posterior limb of the internal capsule, which is echogenic. The head of the caudate nucleus is echolucent and lies lateral to the cavum septum pellucidum (Fig. 3). Level 4 is a measurement taken at the level of the midbrain, which appears as a heart-shaped structure consisting of the cerebral peduncles which are echodense, and the red nuclei and mamillary fasciculi which are echolucent. This measurement is taken at the level where the basilar and posterior cerebral arteries can be seen pulsating. The basilar artery can be located in the notch of the heart-shaped structure, as first described by JOHNSON [6]. The posterior cerebral arteries can be seen pulsating approximately 1 cm anterior and 1.5 cm lateral to the basilar artery. The MB measurement was taken

Fig. 1. Sonogram taken at level 1, at the level of the fetal anterior horns.
A. Anterior horn.

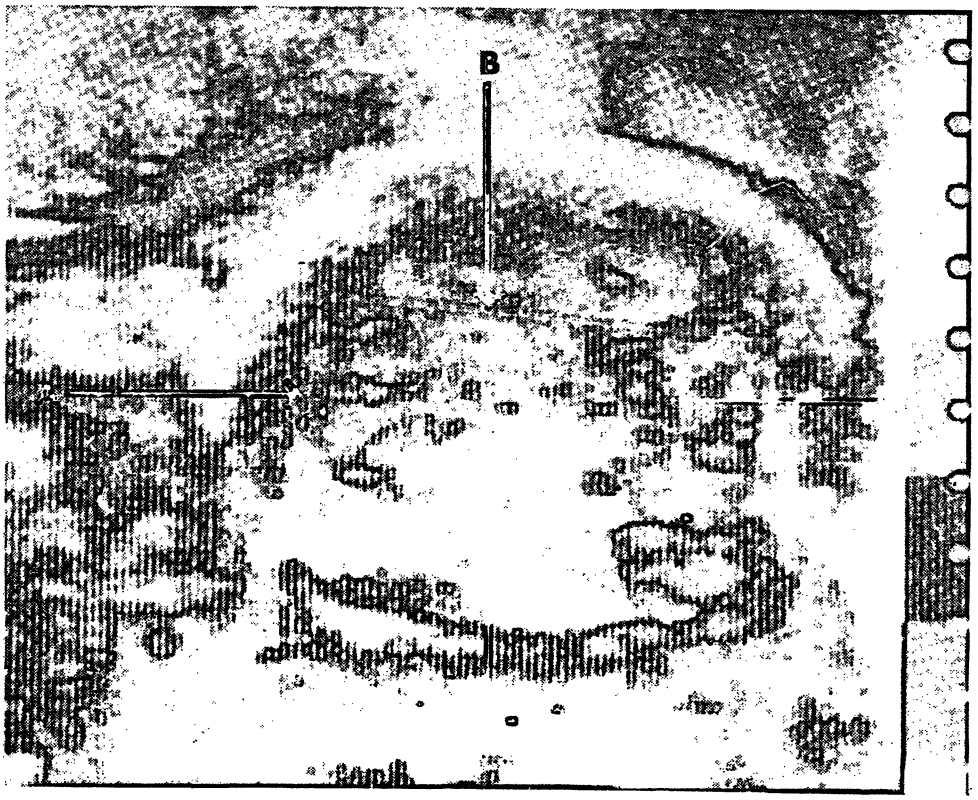

Fig. 2. Sonogram taken at level 2, the level of fetal maximum ventricular length and width.
A. MVL – B. MVW

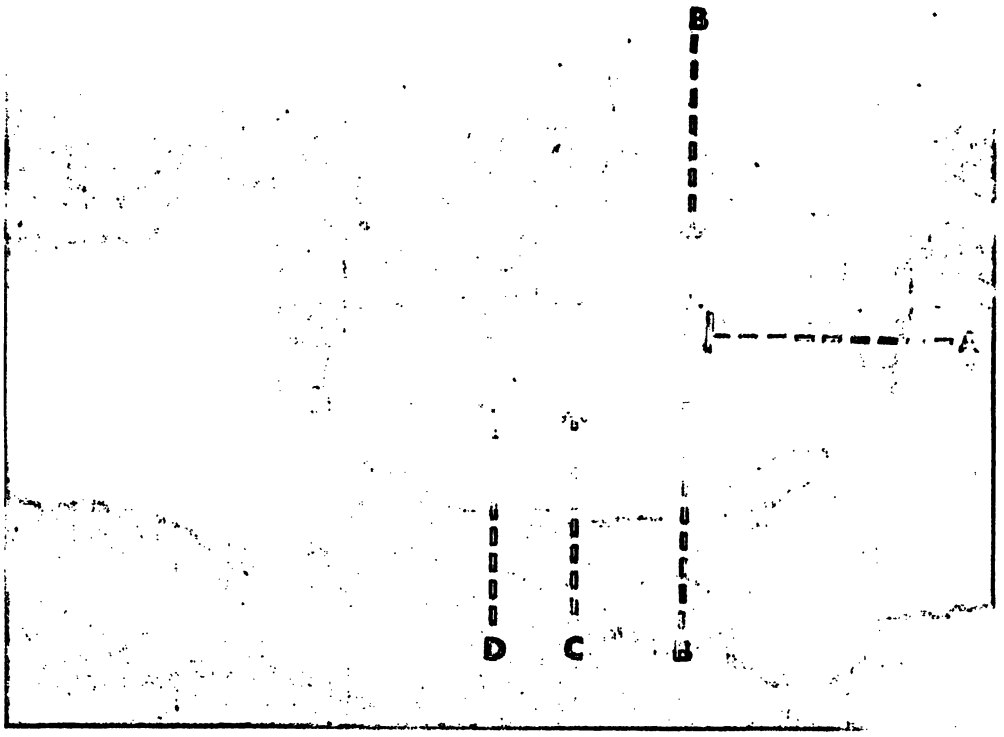

Fig. 3. Sonogram at the level of the fetal biparietal diameter.
A. Cavum septum pellicudum. B. Head of the caudate nucleus. C. Thalmus. D. Poterior limb of the internal capsule.

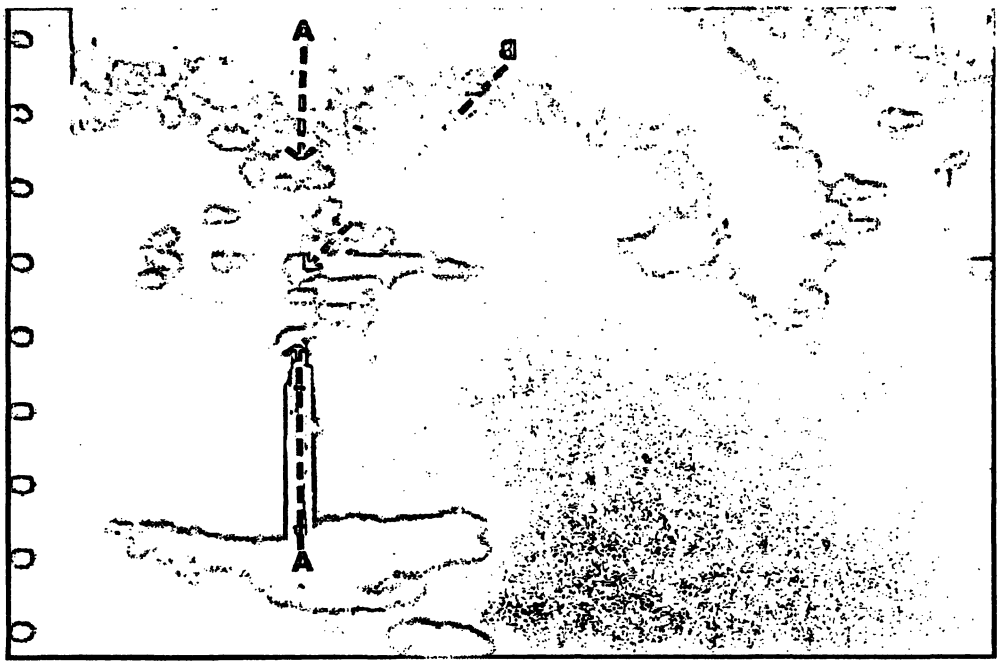

Fig. 4. Sonogram taken at the level of the fetal midbrain.
A. Midbrain consisting of echodense heart-shaped cerebral peduncles surrounding the echolucent red nuclei and mamillary fasiculi. B. Basilar artery which appears as a pulsatile structure using real time ultrasonography.

to be the maximum transverse diameter of the cerebral peduncles transecting the basilar artery (Fig. 4). Anatomical correlation was done by sectioning the fixed neonatal brain at different gestational ages at the same four levels used for sonographic measurements.

3 Results and discussion

The cerebral vasculature and nuclei were used as landmarks for locating various anatomical structures. The basilar, anterior, middle, and posterior cerebral arteries can be identified and followed to their origin in the Circle of WILLIS sonographically. Anatomical correlation with the gross brain at different gestational ages was used for more accurate identification of the various neuroanatomical structures. In the fixed brain, the ventricles appear smaller than the measurements obtained in utero sonographically.

The AH measurements represent the anterior horn and the sonolucent genu of the corpus callosum, which lies between the sonodense lines. The AH measurements are easily obtained and increase from 1 cm at 15–20 weeks to 2.4 cm at 36–38 weeks (Tab. I). The measurements of the MVL and MVW include the lateral ventricles and the sonolucent areas of the corpus callosum, head of the caudate nuleus and the thalamus, which are anatomically related in vivo. The MVL increased from a mean of 2.7 cm at 15–20 weeks to 5.3 cm at 36–38 weeks. The MVW increased from 1.9 cm at 15–20 weeks to 3 cm at 36–38 weeks (Tab. II). As the fetus matures, the MVW/BPD ratio decreased from 0.5 at 15–20 weeks to 0.3 at 36–38 weeks.

Tab. I. Measurements of the fetal anterior horn, midbrain and AH/ BPD ratio

Weeks	BPD	Anterior Horn	Mid Brain	AH BPD
15–20 T (20)	3.9	1.0	–	0.5
21–24 T (23)	5.5	1.4	1.4	0.7
25–27 T (25)	6.4	1.6	1.6	0.7
28–29 T (11)	6.9	1.8	1.8	0.7
30–31 T (22)	7.4	1.9	1.9	0.8
32–33 T (25)	7.9	2.1	2.1	0.8
34–35 T (15)	8.4	2.3	2.3	0.8
36–38 T (15)	9.0	2.4	2.3	0.8

The MVL/BPD is 0.7 at 15–20 weeks and remains constant at 0.6 cm at 25 weeks to term. The MVW/MVL ratio was 0.7 at 15–20 weeks and remained constant at 0.6 cm to term. The AH/ BPD ratio increased from 0.5 cm at 15–20 weeks to 0.8 cm at term. The MB measurements could not be obtained between 16–20 weeks as the lateral ventricles are filled with the echodense choroidal plexus and therefore are difficult to outline. They increased from 1.4 cm at 21–24 weeks to 2.3 cm at term.

In a 28-year-old GIPO woman with sickle trait whose husband also has sickle trait, an ultrasound was performed at 18.5 weeks for the antenatal diagnosis of sickle cell anemia by DNA endonuclease analysis, with amniocentesis. The ultrasound revealed a twin gestation. Both twins had a BPD of 4.1 consistent with her dates. Ultrasonic evaluation revealed Twin A in the vertex position with a BPD of 4.7 cm, and Twin B in the breech position with a BPD of 4.9 cm. A repeat sono-

Tab. II. Measurements of the cerebral ventricles in the intrauterine fetus

Weeks	BPD	MAX Length	MAX Width	MAX W / MAX L	MAX W / BPD	MAX L / BPD
15–20 T (20	3.9	2.7	1.9	0.7	0.5	0.7
21–24 T (23)	5.5	3.6	2.1	0.6	0.4	0.7
25–27 T (25)	6.4	3.9	2.2	0.6	0.4	0.6
28–29 T (11)	6.9	4.1	2.3	0.6	0.3	0.6
30–31 T (22)	7.4	4.4	2.4	0.6	0.3	0.6
32–33 T (25)	7.9	4.7	2.5	0.5	0.3	0.6
34–35 T (15)	8.4	5.1	2.9	0.6	0.3	0.6
36–38 T (15)	9.0	5.3	3.0	0.6	0.3	0.6

gram was done at 20 weeks. Twin B's ventricles appeared to be echolucent with minimal choroid visible. The ventricular length and width were noted to be substantially increased. The MVL was 4.9 cm (normal mean 2.7) and MVW 4.0 (normal mean 1.9). The key ratios were also abnormal, with MVW/BPD = 0.8 (normal 0.5), MVL/BPD = 0.9 (normal 0.7) and MVW/MVL = 0.8 (normal 0.7) (Tab. III). These valuable parameters were useful in the early diagnosis of hydrocephalus before the enlargement of the BPD. Studies showed that Twin A was sickle negative, and Twin B had SS disease. At 25 weeks a discrepancy in BDP's was noted, 7.3 cm for Twin B, and a normal measurement for Twin A of 6.1 cm. Premature labor at 29 weeks occurred with vaginal delivery of Twin A as a NSVD, and assisted breech delivery with needle decompression of the hydrocephalic Twin B.

Previously, it was thought that the intrauterine diagnosis of hydrocephalus was dependent on a BPD greater than 11 cm at term. With the improved resolution of real time ultrasound, the ventricular system was studied by various investigators and stricter criteria were set [6]. The diagnosis of hydrocephalus before 20 weeks only can be made using strict criteria, since the echodense ventricles filled with choroid plexus occupy a relatively large proportion of the intracranial volume. Echolucent ventricles prior to 20 weeks may raise the suspicion of hydrocephalus, but diagnosis cannot be made on this alone. It is of great importance to note that prior to 24 weeks gestation ventricular enlargement can occur before an increase in BPD, as observed in the set of twins presented.

In the evaluation of the ventricular system errors in interpretation and measurement may lead to inappropriate action. The Sylvian fissures may be mistaken for the outer border of the lateral ventricle [6]. The middle cerebral artery, which can be identified from its origin at the Circle of WILLIS, can be followed to the Sylvian fissure where it may be seen pulsating, and thus help distinguish between the two structures. When the head is fixed on the pelvis reverberation echos from the bone may cause artifacts resembling cystic areas and areas of increased echogenicity. Such artifacts occur frequently and must be interpreted correctly rather than overdiagnosing hydrocephaly. Unless the accurate visualization of the cerebral anatomy is possible no specific measurements or diagnosis should be made. Thus, identification of anatomical landmarks, and measurements at the correct levels are paramount for proper diagnosis.

Tab. III. Ultrasonic evaluation of the fetal cerebral ventricular system in a set of twin with the early diagnosis of hydrocephalus in Twin B

	Weeks	BPD	MAX / L	MAX / W	AH	B	MAX W / MAX L	MAX W / BPD	MAX L / BPD
Twin A	18	4.1							
Twin B	18	4.1							
Twin A	20.5	4.7							
Twin B	20.5	4.9	4.9	4.0			0.8	0.8	0.9
Twin A		5.8	3.9	2.1	1.3	1.3	0.6	0.4	0.7
Twin B		6.0	6.0	4.5			0.8	0.8	1.0
Twin A	27	6.1	4.0	2.2	1.6	1.8	0.6	0.4	0.7
Twin B	27	7.3	6.4	5.0	3.9	2.1	0.8	0.7	0.9
Twin A	28	6.9	4.4	2.3	1.8	1.8	0.5	0.3	0.7
Twin B	28	8.1	7.1	6.0		2.1	0.9	0.8	0.9
Twin A	29	Head in pelvis							
Twin B	29	9.1	8.1	7.0			0.9	0.8	0.9

In studying the early detection of hydrocephalus in the preterm infant, the AH is the last area to dilate and enlarges significantly in normals. Therefore, it is not an ideal measurement for the early diagnosis of hydrocephalus. In our case of intraventricular hemorrhage diagnosed in utero [7], the third ventricle and lateral ventricles were markedly dilated, while the AH, completely filled with blood, did not dilate to the same extent. Thus, the AH measurement adds little to the early diagnosis of hydrocephaly. JOHHNSON et al. measured the lateral ventricles' width (LVW) and hemispheric width (HW) and the LVW/HW ratio was calculated for the different gestational ages. HADLOCK et al. showed that the third ventricle is not routinely visualized before 34 weeks in the absence of hydrocephaly, disagreeing with DENKHAUS and WINSBERG. A lateral ventricular ratio greater than 0.45 (bodies) or greater than 0.65 (atrium) is suggestive of hydrocephalus in that study. The present study confirms that the lateral ventricular width is a sensitive parameter for evaluating early cases of hydrocephalus. Since hydrocephalus may be amenable to treatment in utero [1, 2], early diagnosis and serial evaluation are important. The present study demonstrates the usefulness of lateral ventricular length and the ratios of MVL/BPD and MVW/BPD as well. The study delineates the limits of normal fetal ventricular development at different gestational ages, correlating the sonographic sections with the corresponding sections through the fixed neonatal brain for anatomical accuracy. In addition to previous measurements, MVL, MVW, MVL/BPD, MVW/BPD offer a combination of parameters for the early and accurate diagnosis of hydrocephaly, as well as other anomalies of the fetal brain.

Summary

Real time ultrasound was used to evaluate the anatomy of the fetal brain at different gestational ages. Anatomical correlation with the gross brain was utilized for more accurate identification of the neuroanatomical structures. The normal growth of the ventricular system was studied. Transaxial measurements of the anterior horn (AH) and maximum ventricular length (MVL) and width (MVW) were made, and enlarged as pregnancy progressed. The ratios of MVW/MVL, MVL/BPD, and MVW/BPD provide guides to the early diagnosis of hydrocephalus and intracranial abnormalities. Specific measurements of the cerebral ventricles at various gestational ages may be made accurately by utilizing the anatomical landmarks. The anterior horn and midbrain measurements are of little value in the early diagnosis of hydrocephaly. Maximum ventricular length and width are the most useful determinants of hydrocephaly, even as early as 20 weeks. A set of discordant twins in which twin B was found to be hydrocephalic by these studies in the twentieth week is presented with serial measurements for both twins. Multiple measurements of the cerebral ventricular system in utero permit early and precise diagnosis of fetal hydrocephaly.

Keywords: Anterior horn, fetal cerebral ventricles, maximum ventricular length and width, midbrain.

Zusammenfassung

Sonographische Darstellung der fetalen Hirnventrikel und ihre Bedeutung für die Frühdiagnose eines Hydrocephalus
Der Real-Time-Ultraschall wurde zur Untersuchung der Anatomie des fetalen Gehirns zu unterschiedlichen Zeitpunkten der Schwangerschaft eingesetzt. Dabei wurden zur genaueren Indentifizierung der neuroanatomischen Strukturen die anatomische Beziehung zum Großhirn berücksichtigt sowie die normale Größe des Ventrikelsystems untersucht. Wir haben transaxiale Messungen am Vorderhorn sowie Messungen der maximalen Länge (MVL) und maximalen Weite (MVW) durchgeführt, wobei die Werte mit dem Schwangerschaftsalter zunahmen. Die Quotienten aus MVW/MVL, MVL/BPD und MVW/BPD geben Hinweise für die Frühdiagnose eines Hydrocephalus bzw. intracranieller Anomalien. Spezifische Messungen an den Hirnventrikeln zu verschiedenen Zeitpunkten der Schwangerschaft können unter Einbeziehung anatomischer Marker genauer ausgeführt werden. Vermessungen des Vorderhorn und des Mittelhirns sind für die Frühdiagnose eines Hydrocephalus von untergeordneter Bedeutung; die maximale Länge bzw. Weite liefern dagegen schon ab der 20. Woche gute Hinweise. Wir untersuchten ein diskordantes Zwillingspaar, bei dem Zwilling B nach unseren Werten einen Hydrocephalus in der 20. Schwangerschaftswoche aufwies und führten wiederholt Messungen bei beiden Zwillingen durch. Häufige Messungen des Hirnventrikelsystems in utero erlauben eine frühe und genaue Diagnose eines fetalen Hydrocephalus.

Schlüsselwörter: Fetale Hirnventrikel, maximale Ventrikellänge und -weite, Mittelhirn, Vorderhorn.

Résumé

Anatomie ultrasonore des ventricules cérébraux du fœtus diagnostic précoce de l'hydrocéphalie

On a utilisé les ultrasons en temps réel pour évaluer l'anatomie du cerveau fœtal aux différents âges gestationnels. On a effectué des corrélations anatomiques avec le cerveau global pour une identification plus fine des structures neuroanatomiques. On a pratiqué les mesures transaxiales de la corne antérieure (CA), de la longueur et de la largeur ventriculaire maximale (MVL et MVW). Les rapports MVW/MVL, MVL/BPD et MVW/BPD assurent un guide pour le diagnostic précoce de l'hydrocéphalie et des anomalies intracrâniennes. Les mesures spécifiques des ventricules cérébraux à des termes gestationnels variés peuvent être effectuées des façon appropriée en utilisant les repères anatomiques. Les mesures de la corne antérieure et du cerveau moyen sont de peu de valeur pour le diagnostic précoce d'hydrocéphalie. La longueur et la largeur maximales des ventricules sont les paramètres les plus utiles dans l'hydrocéphalie, même dès 20 semaines. Un ensemble de jumeaux discordants, dans lequel le jumeau B a été trouvé hydrocéphale par ces mesures au cours de la 20ème semaine est présenté avec des mesures répétées pour chacun des jumeaux. Les mesures multiples in utero du système ventriculaire cérébral autorisent le diagnostic précoce et précis de l'hydrocéphalie fœtale.

Mots-clés: Cerveau moyen, corne antérieure, longueur et épaisseur maximales des ventricules, ventricules cérébraux du fœtus.

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